US007358684B2

(12) United States Patent
Wey et al.

(10) Patent No.: US 7,358,684 B2
(45) Date of Patent: *Apr. 15, 2008

(54) **BALANCED CIRCUIT FOR MULTI-LED DRIVER**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **11/707,483**

(22) Filed: **Feb. 15, 2007**

(65) **Prior Publication Data**

US 2007/0152606 A1 Jul. 5, 2007

Related U.S. Application Data

(62) Division of application No. 11/156,288, filed on Jun. 16, 2005, now Pat. No. 7,196,483.

(51) **Int. Cl.**
H05B 41/24 (2006.01)
H05B 37/00 (2006.01)

(52) **U.S. Cl.** **315/277**; 315/312

(58) **Field of Classification Search** .... 315/200 R, 315/201, 205, 206, 255, 256, 277–278, 291, 315/312; 362/800, 806, 812
See application file for complete search history.

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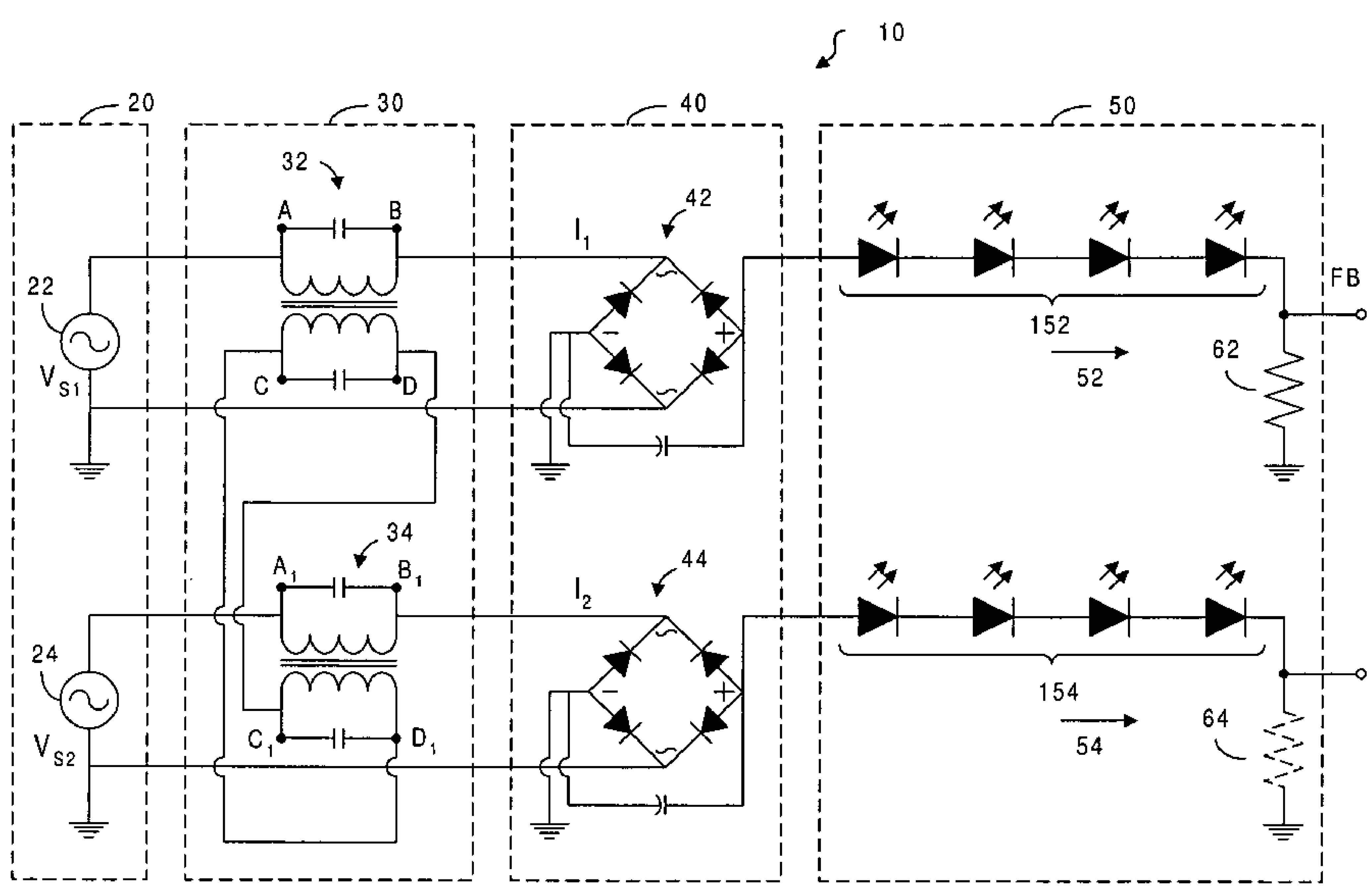
(57) **ABSTRACT**

A driving circuit uses a plurality of transformers to provide currents for driving a plurality of LEDs associated with a plurality of current paths. Each transformer has two induction coils with a coil turn ratio between to the number of turns in each induction coil. One induction coil is used to provide an output current to a different current path and the other induction coil is connected to the corresponding induction coil of other transformers for forming a current loop. The output current of each transformer has a relationship with the output current of the other transformers depending on the coil turn ratios of the connected transformers. LEDs in red, blue and green colors can be connected to different current paths so that the brightness of the LEDs in each color can be determined by the current in a current path.

4 Claims, 10 Drawing Sheets



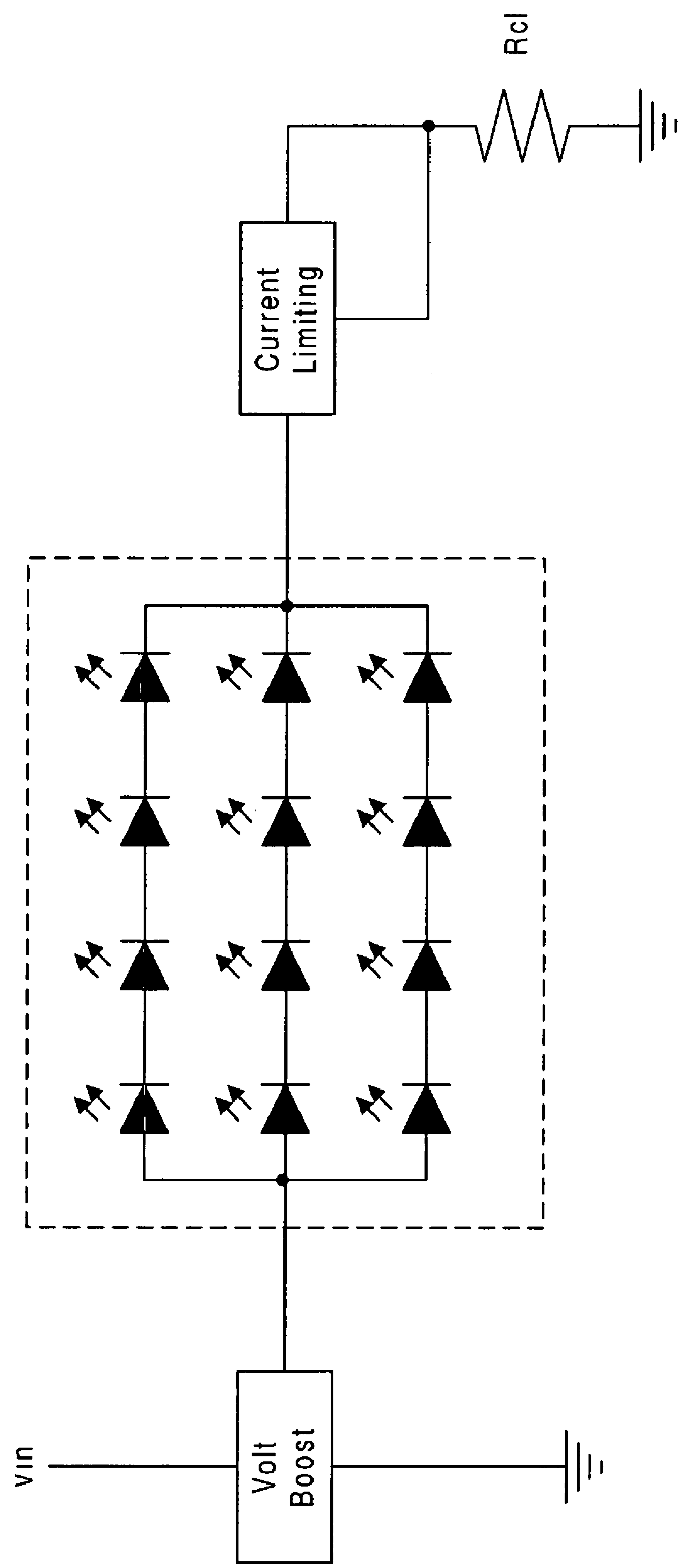


FIG. 1
(prior art)

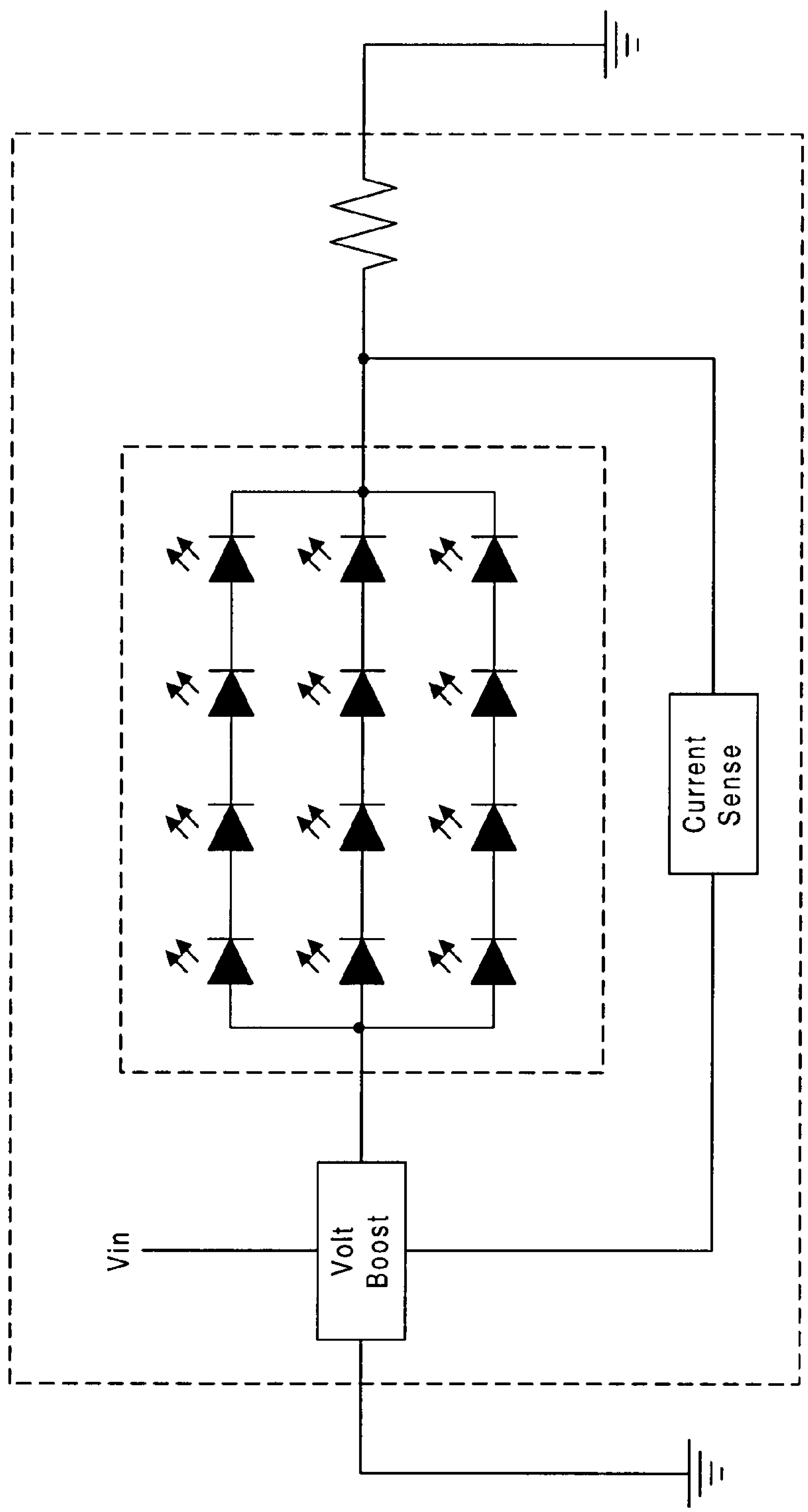


FIG. 2
(prior art)

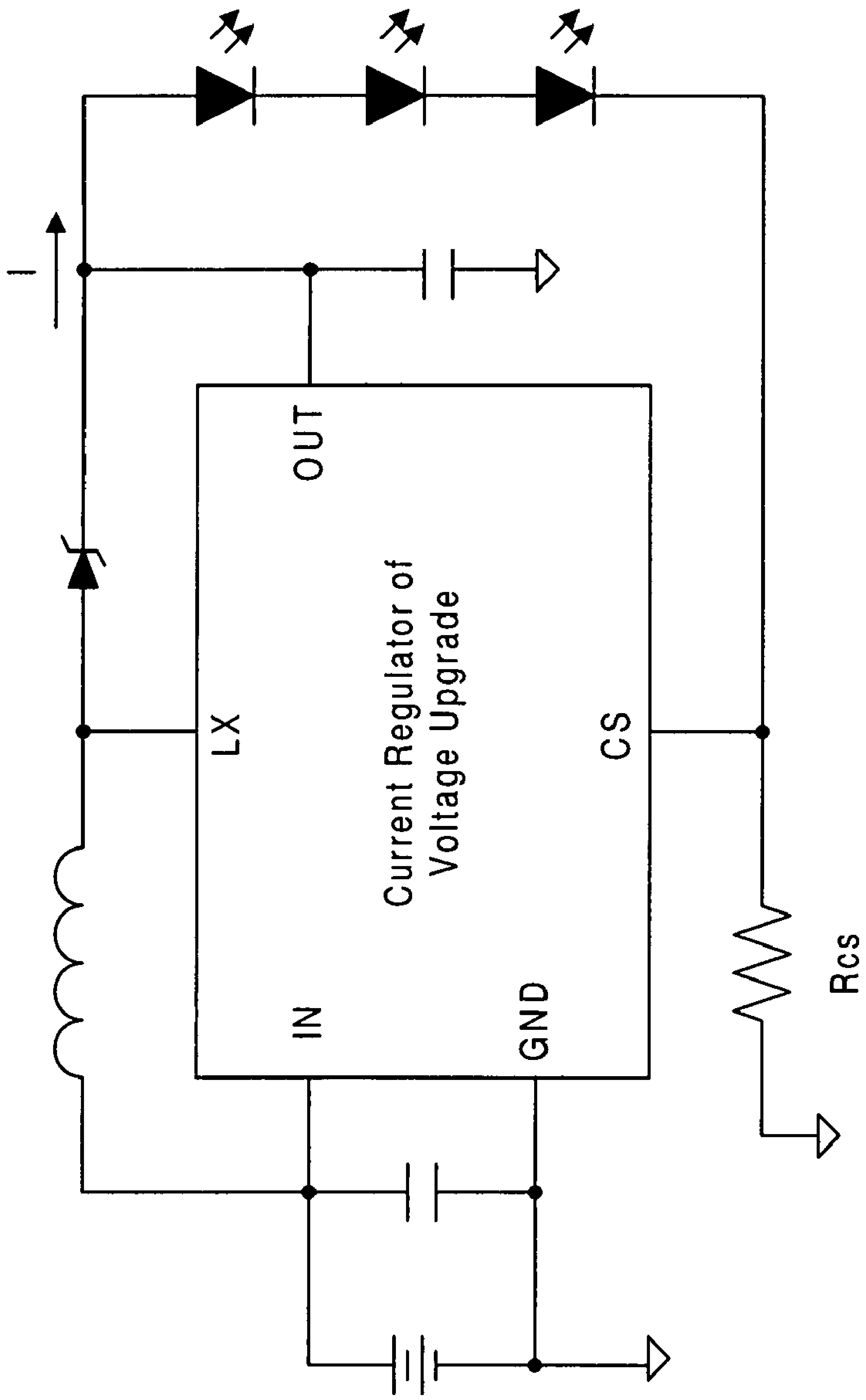
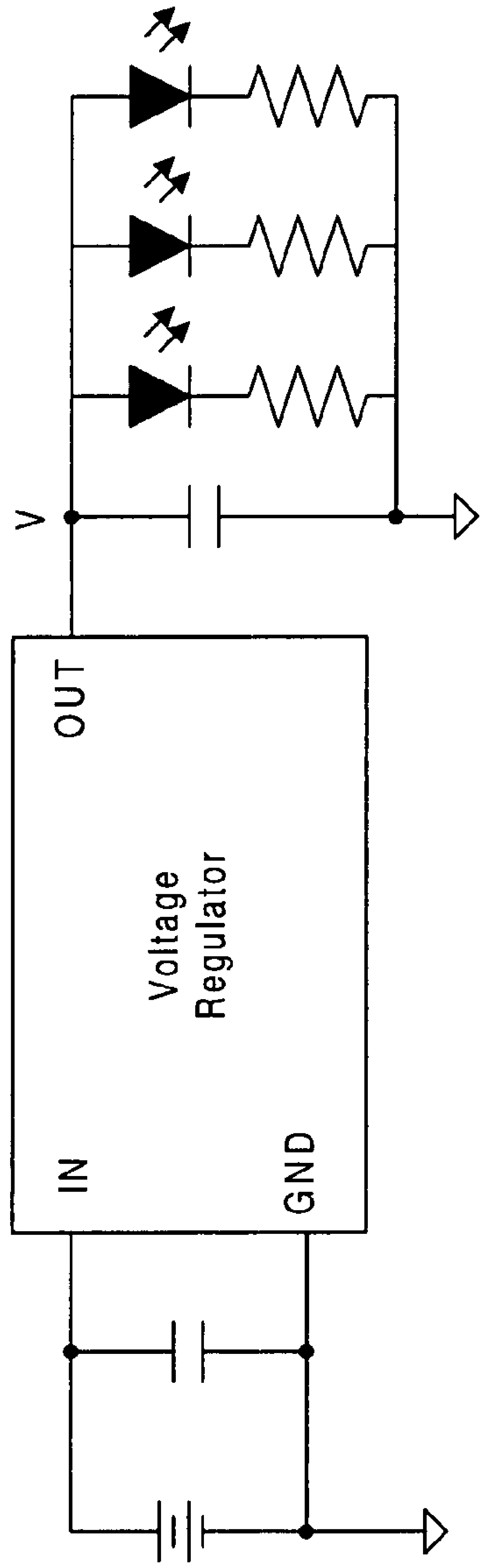


FIG. 3
(prior art)

FIG. 4
(prior art)



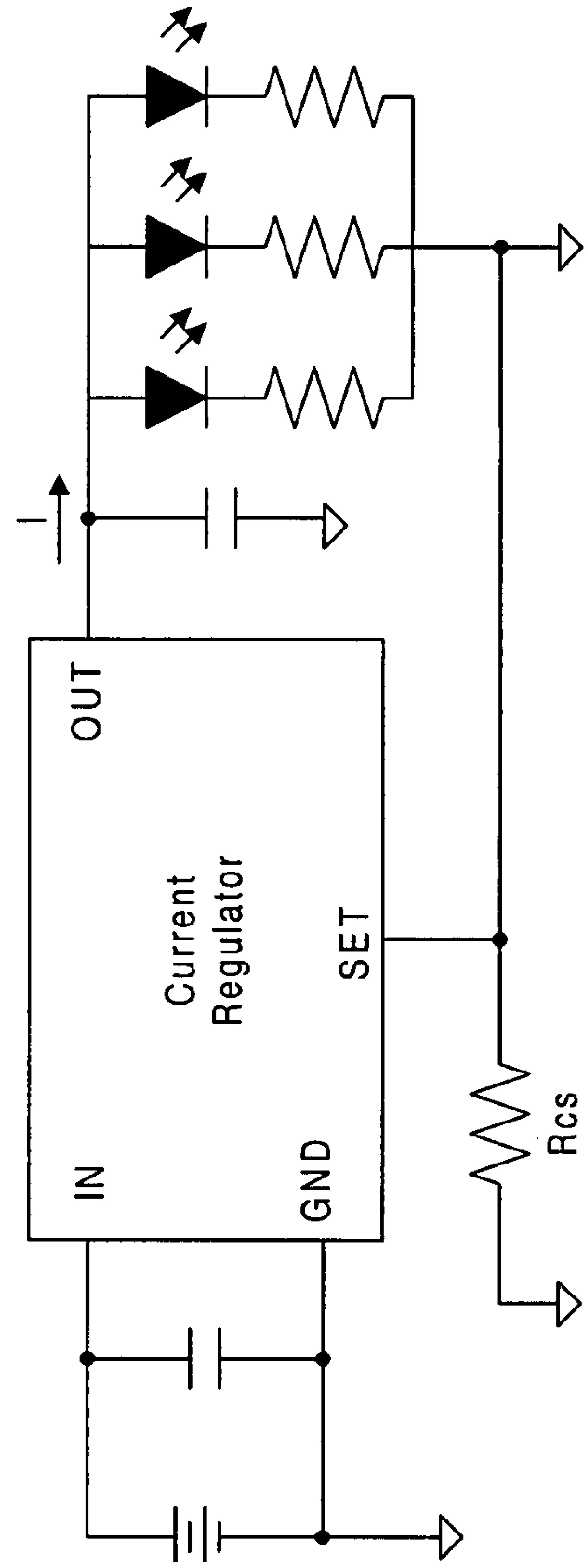


FIG. 5
(prior art)

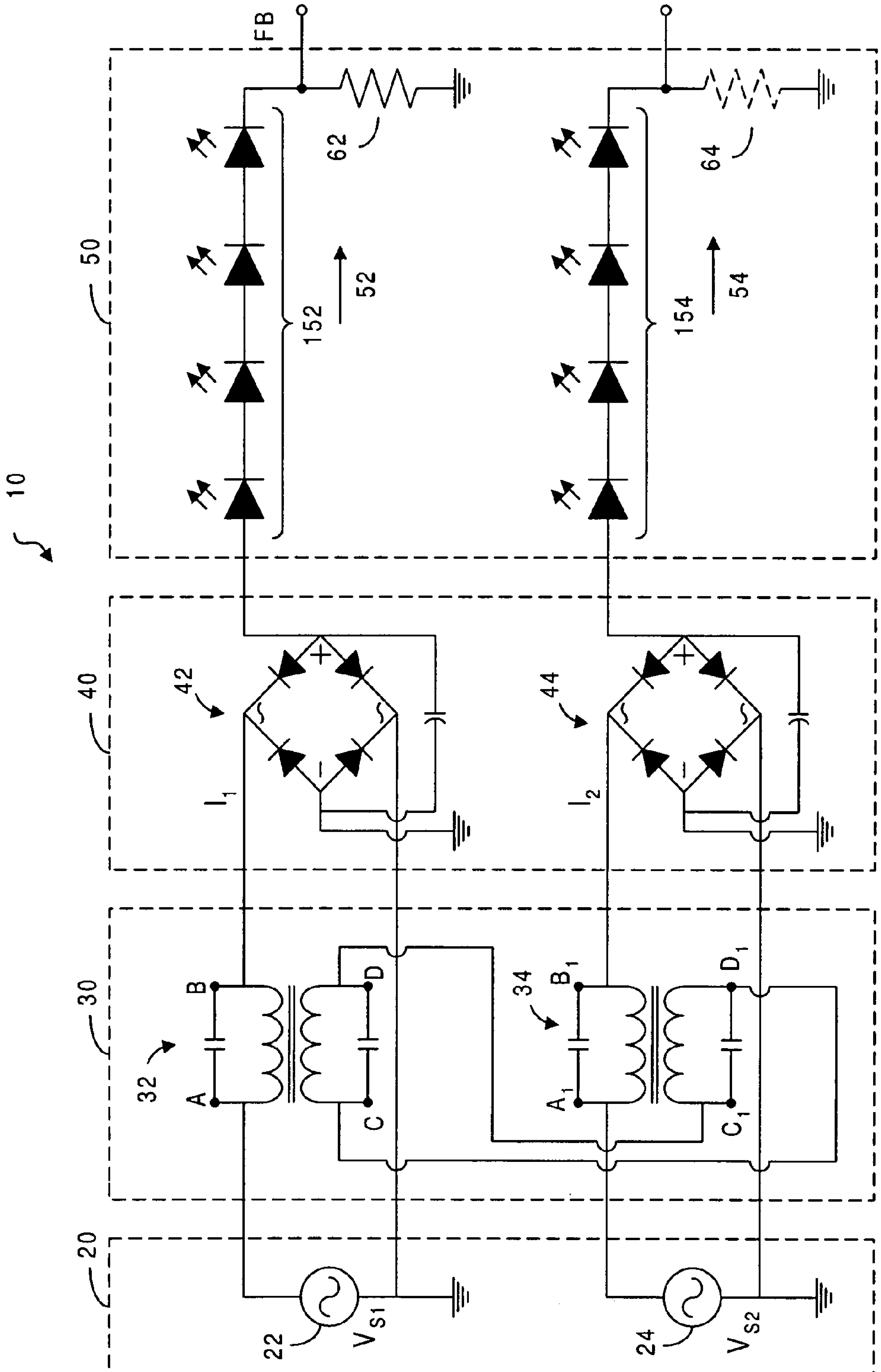
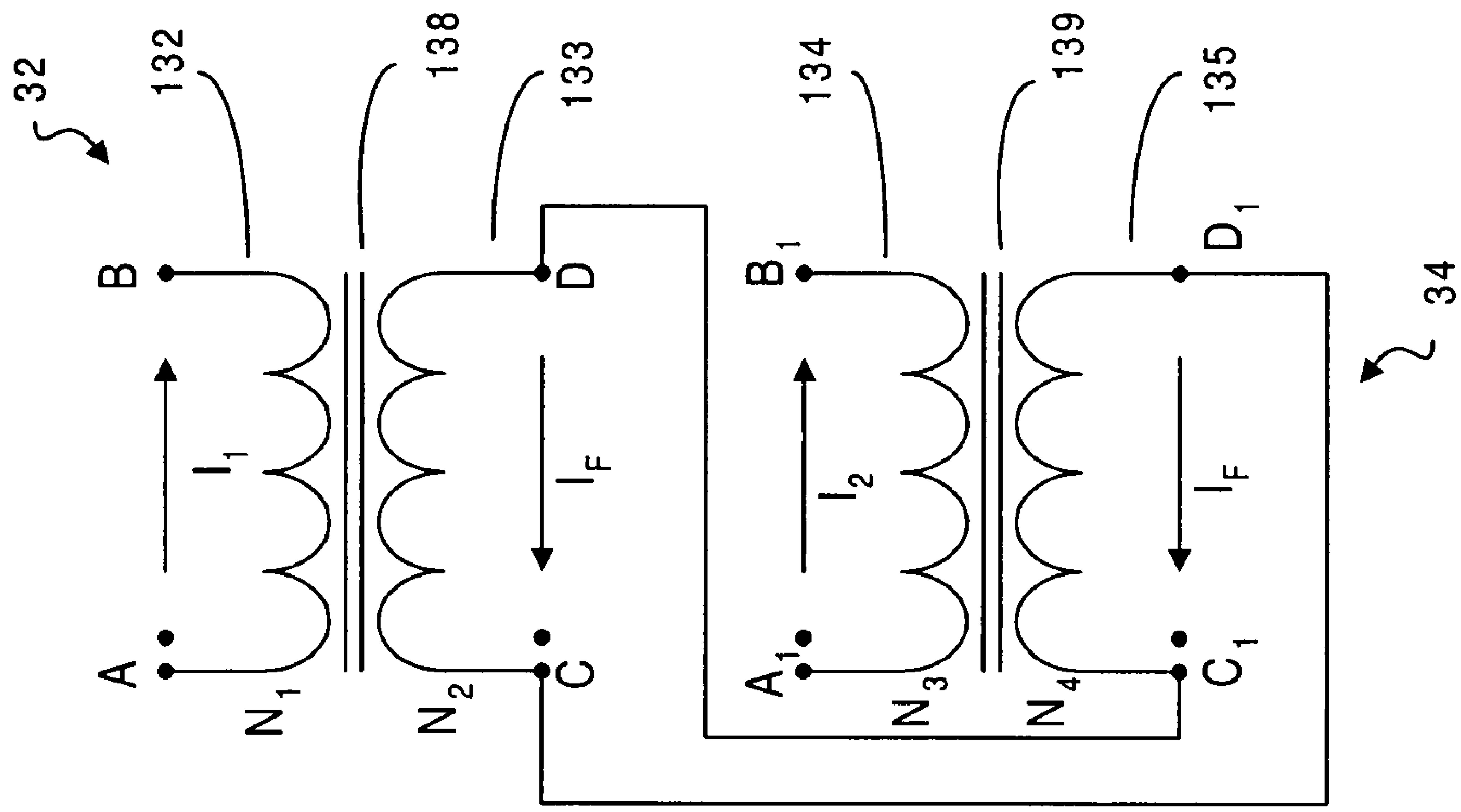

10
20
22
24
V_{S1}
V_{S2}
30
32
34
A
B
C
D
A_1
B_1
C_1
D_1
40
42
44
I_1
I_2
50
52
54
152
154
62
64
FB

FIG. 6

FIG. 7


32
132
138
133
134
139
135
34
A
B
C
D
A1
B1
C1
D1
N1
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N3
N4
I1
I2
IF
IF

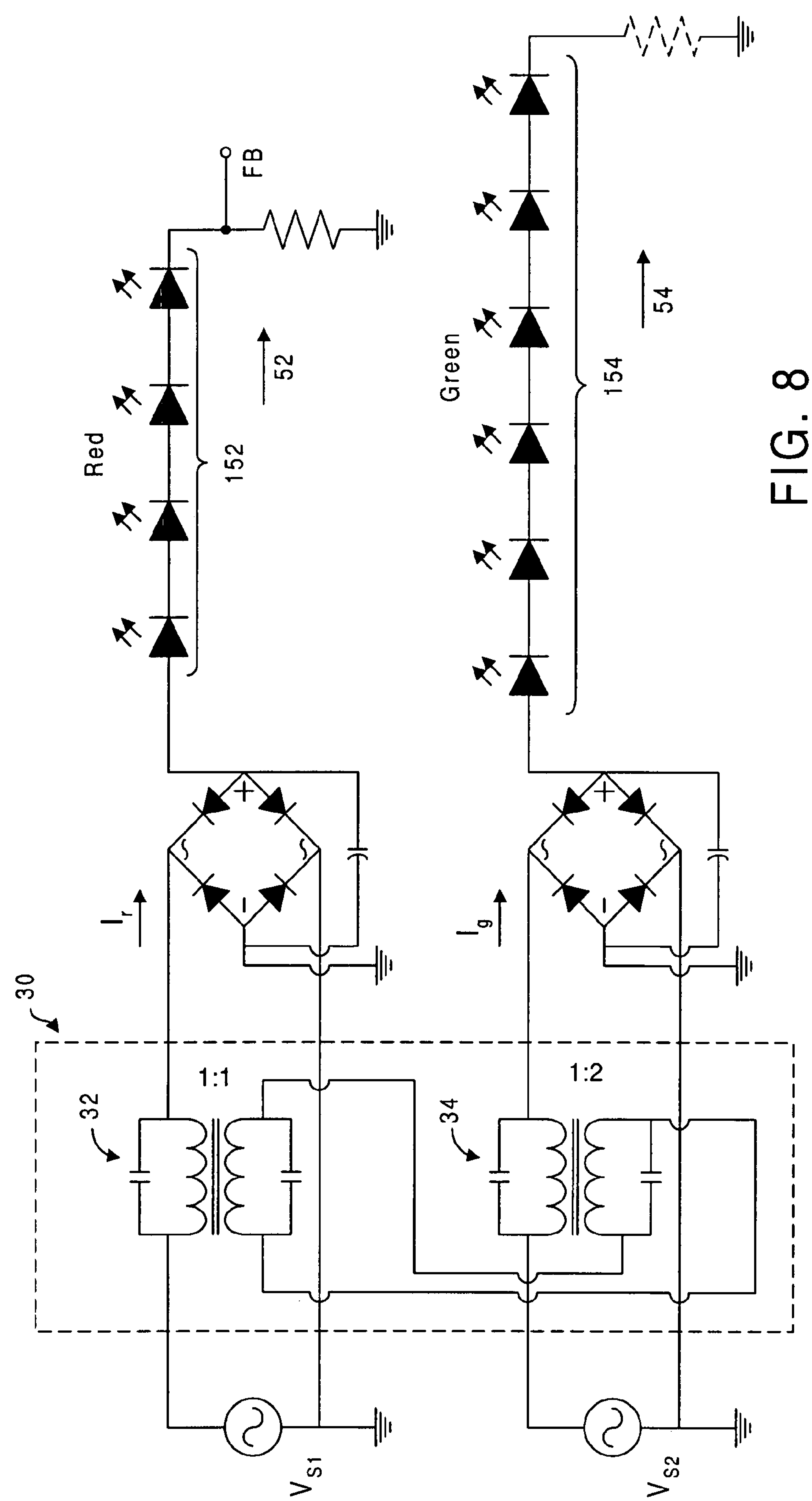

FIG. 8

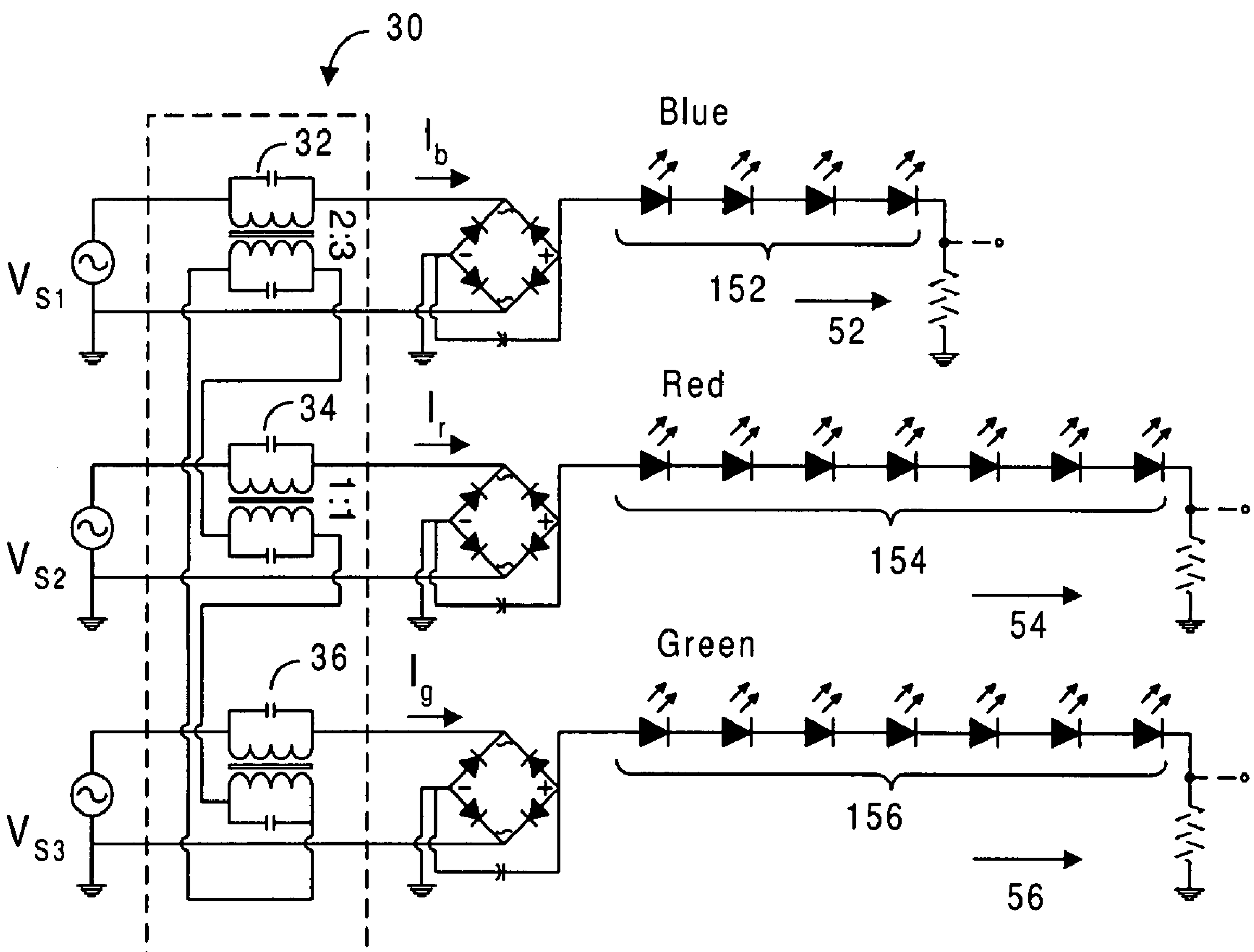
30
32
2:3
I_b
Blue
152
52
V_{S1}
34
1:1
I_r
Red
154
54
V_{S2}
36
I_g
Green
156
56
V_{S3}

FIG. 9

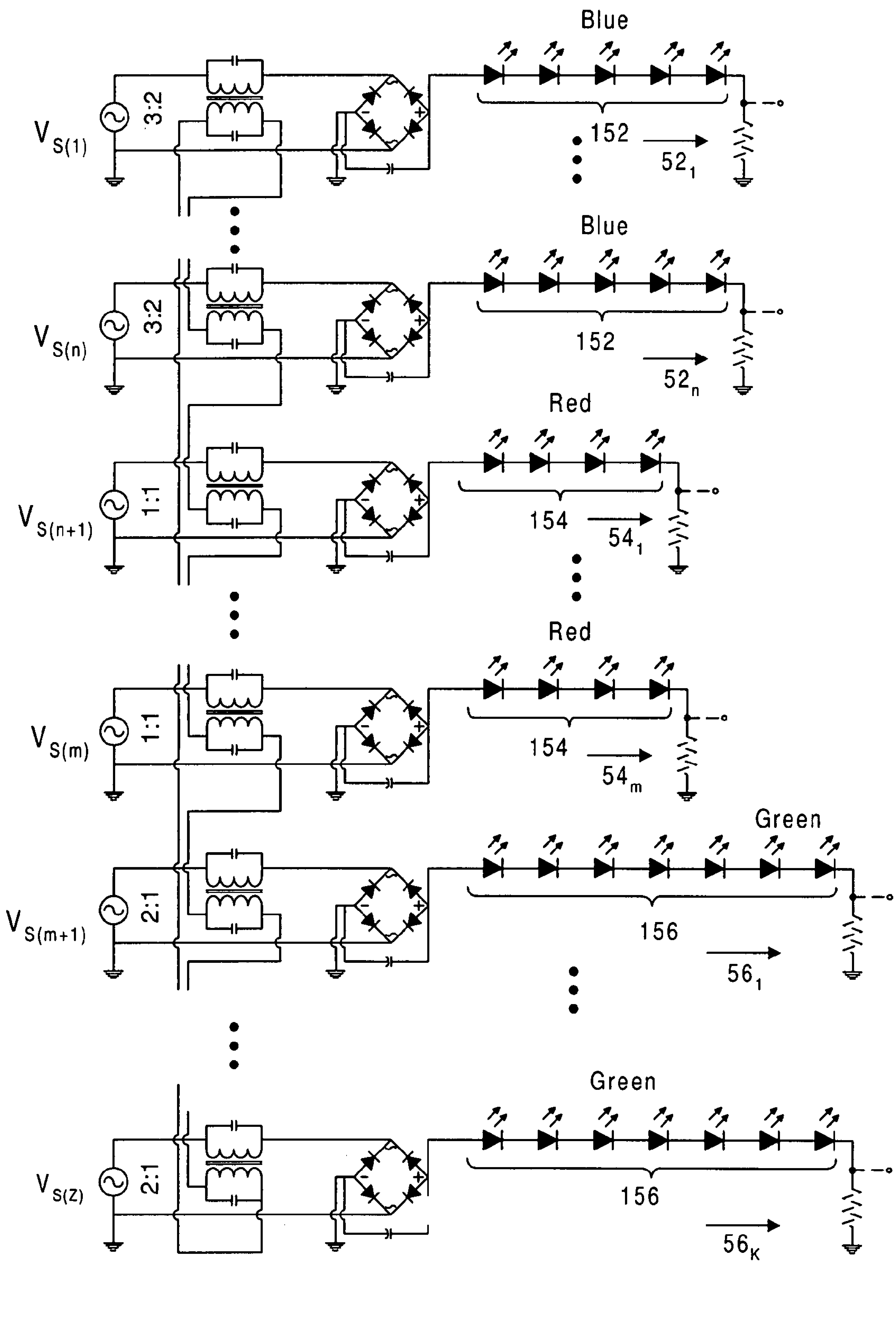
Blue
V S(1)
3:2
152
52 1
Blue
V S(n)
3:2
152
52 n
Red
V S(n+1)
1:1
154
54 1
Red
V S(m)
1:1
154
54 m
Green
V S(m+1)
2:1
156
56 1
Green
V S(Z)
2:1
156
56 K

FIG. 10

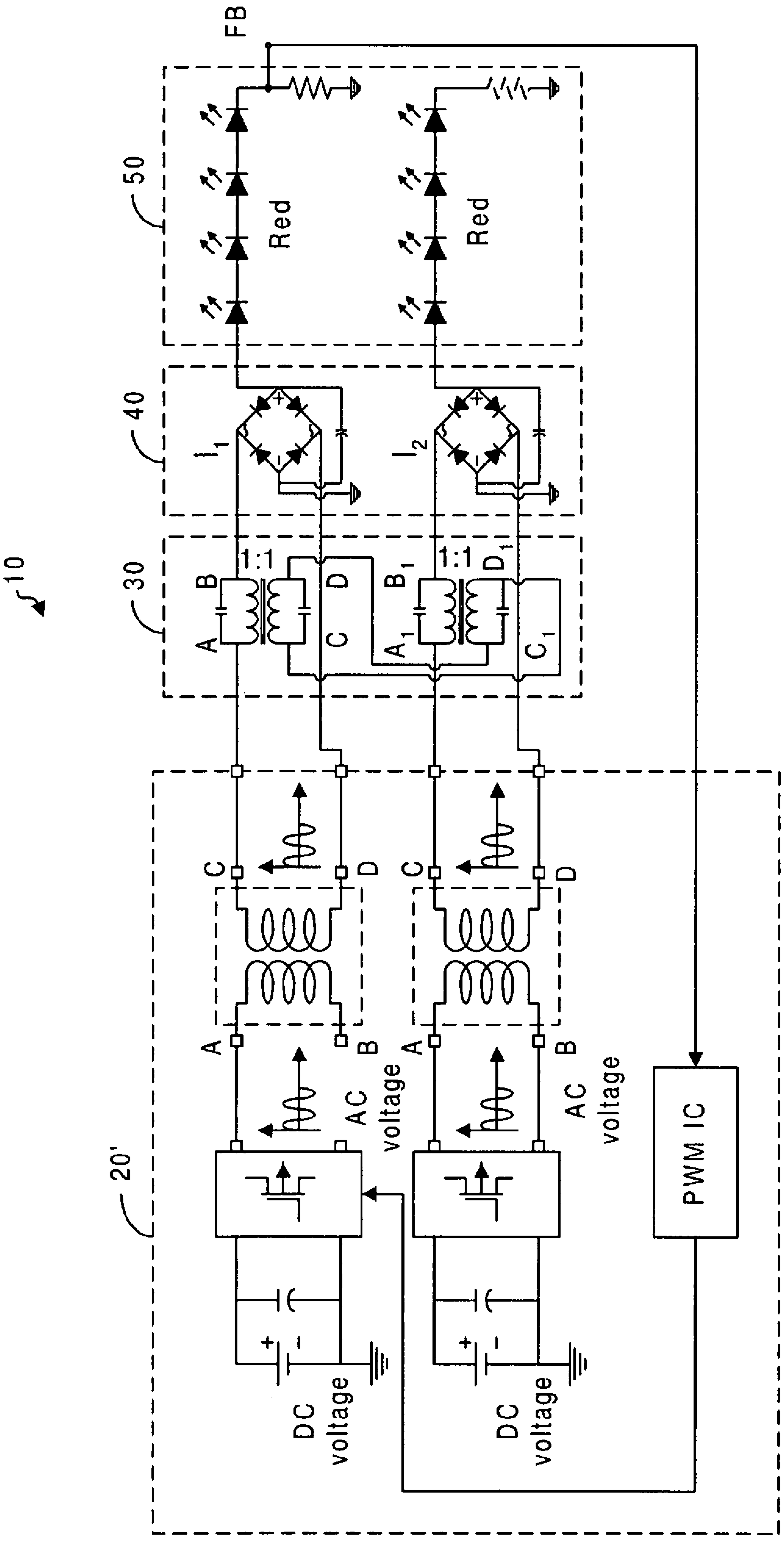
10
FB
50
Red
Red
40
I_1
I_2
30
1:1
1:1
A
B
C
D
A_1
B_1
C_1
D_1
A
B
C
D
A
B
C
D
20'
AC voltage
AC voltage
DC voltage
DC voltage
PWM IC

FIG. 11

BALANCED CIRCUIT FOR MULTI-LED DRIVER

This application is a DIV of Ser. No. 11/156,288 Jun. 16, 2005 U.S. Pat. No. 7,196,483.

FIELD OF THE INVENTION

The present invention relates generally to a driving circuit for driving a plurality of light-emitting devices and, more particularly, to a driving circuit having a plurality of current paths each of which is connected to one or more light-emitting devices.

BACKGROUND OF THE INVENTION

Light-emitting devices (LEDs) are commonly used in a back-lighting source for a liquid crystal display (LCD) panel. In particular, LEDs in red, green and blue colors are used to provide a back-lighting source in "white" color. In prior art, when a driving circuit is used to drive a display having one or more strings of light-emitting devices (LEDs), these strings are connected in parallel to form a single current supply path. As shown in FIG. **1**, a current limiting device and a current limiting resistor Rcl are used to regulate the total current in the current supply path. In such a driving circuit, a voltage boosting device is used as a power supply to supply the current to the LEDs. Alternatively, a current sensing device is used to provide a feedback to the voltage boosting device in order to regulate the total current in the current supply path, as shown in FIG. **2**.

In the driving circuits as shown in FIGS. **1** and **2**, it is assumed that the current through each of the string of LEDs is substantially the same. However, because the non-linear relationship between the voltage drop and the current in an LED, one or more slightly irregular LEDs in a string may cause the current through that LED string to increase significantly. As such, the useful operational life of the LEDs in that string may be significantly shortened. If the strings of LEDs are used to provide in a white back-lighting source, the color balance in the back-lighting source may be shifted because the brightness in one string is different from the brightness in other strings.

It is possible to use a separate driving circuit for each string of LEDs. For example, a current regulator with a voltage upgrade feature can be used to regulate the current through the LED string. As shown in FIG. **3**, the current regulator regulates the current by sensing the voltage across the current sensing resistor Rcs. While this type of current regulator is very effective in regulating current, it is not a cost-effective solution. Furthermore, this type of current regulator produces a significant amount of electromagnetic radiation that could be a problematic source of electromagnetic interference (EMI).

Alternatively, a group of LEDs of the same color can be connected in parallel and each parallel current path has a separate current limiting resistor in a voltage regulator as shown in FIG. **4** and in a current regulator as shown in FIG. **5**. However, the electrical characteristic of the LEDs in each parallel current path must be examined and matched so that the currents through the parallel current paths can be equalized.

It is thus desirable and advantageous to provide a method and a device that is cost effective and effective in regulating the current in each group of color LEDs in a back-lighting source.

SUMMARY OF THE INVENTION

The driving circuit for driving multiple light-emitting devices in a plurality of current paths, according to the present invention, uses a plurality of transformers coupled with each other such that one of the induction coils in each transformer is connected to one of the induction coils of the other transformers and these connected induction coils are connected in series to form a complete current loop. As such, the output current of one transformer has a certain relationship to the output current of the other transformers through mutual inductance. For example, in a driving circuit where only two transformers are used, one of the induction coils of the first transformer is connected to one of the induction coils of the second transformer to form a current loop. The magnetic flux produced by the output current of the first transformer induces a current in the current loop. Likewise, the magnetic flux produced by the output current of the second transformer induces the same current in the current loop. Thus, depending upon the coil turn ratio in each the transformer, the output current of the first transformer has a substantially fixed relationship with the output current of the second transformer. As such, when the driving circuit is used to provide a plurality of current paths, the current in each current path can be selected by the coil turn ratio in a transformer relative to the coil turn ratio of another transformer.

The driving circuit of the present invention can be used in a light source of various colors by using light-emitting devices of desirable colors. For example, the light-emitting devices can have a mixture of red, green and blue light emitting devices so as to produce a white light source. The simplest white light source has a group of red light emitting devices, a group of green light emitting devices and a group of blue light emitting devices to produce red, green and blue color components. The driving circuit for this white light source has three group of current paths, each group for providing the same current to a group of color light-emitting devices. In order to achieve a desired balance among the different color components in the white light source, it is possible to adjust the number of light emitting devices of one or two colors without changing the driving circuit. Furthermore, it is possible to change the transformer coil turn ratios in an inverter driver or to use a pulse width modulator to adjust the current.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a circuit diagram showing a prior art driving circuit.

FIG. **2** is a circuit diagram showing another prior art driving circuit.

FIG. **3** is a circuit diagram showing a prior art current regulator with voltage upgrade.

FIG. **4** is a circuit diagram showing a prior art voltage regulator.

FIG. **5** is a circuit diagram showing another prior art current regulator.

FIG. **6** is a circuit diagram showing an exemplary driving circuit, according to the present invention.

FIG. **7** is a circuit diagram showing the structure of a balanced transformer circuit, according to the present invention.

FIG. **8** is a circuit diagram showing another exemplary driving circuit having two current paths, according to the present invention.

FIG. **9** is a circuit diagram showing another exemplary driving circuit having three current paths, according to the present invention.

FIG. **10** is a circuit diagram showing a generalized driving circuit having a plurality of current paths, according to the present invention.

FIG. **11** is a circuit diagram showing an inverter driver having a pulse width modulator to adjust the current in a driving circuit.

DETAILED DESCRIPTION OF THE INVENTION

The driving circuit with a plurality of current paths for driving a plurality of light-emitting devices (LEDs), according to the present invention, is explained by way of examples as follows. FIG. **6** illustrates a lighting panel having a light source **50** and a driving circuit **10** having two current paths **52**, **54** for driving two groups of LEDs **152** and **154** in the light source. The driving circuit **10** has an inverter driver block **20** operatively connected to a balanced transformer circuit **30** to provide output currents I_1 and I_2 through a rectifier block **40**. The balanced transformer circuit **30** has a first transformer **32** and a second transformer **34** coupled to each other. The rectifier **40** has a first rectifier **42** connected to the first transformer **32** and a second rectifier **44** connected to the second transformer **34**. The inverter driver block **20** has a first inverter driver **22** to supply power to the first transformer **32** and a second inverter driver **24** to supply power to the second transformer **34**.

The coupling between the first and second transformers in the balanced transformer circuit is shown in FIG. **7**. For illustration purposes, each transformer is assumed to be an ideal transformer in that the induction loss in the transformer is negligible such that the current through each of the transformer coils is determined by the coil turn ratio. In particular, the transformer has only two coils. As shown in FIG. **7**, the transformer **32** has a first coil **132** having N_1 turns coupled to a second coil **133** having N_2 turns through a transformer core **138**. The transformer **34** has a first coil **134** having N_3 turns coupled to a second coil **135** having N_4 turns through a transformer core **139**. The second coil **133** of the first transformer is connected to the second coil **135** of the second transformer to form a current loop. If the output current of the first transformer **32** is I_1, then the magnetic flux produced by I_1 through the coil **132** induces an induction current I_F in the coil **133** given by

$$I_F=I_1(N_1/N_2) \quad (1)$$

Likewise, if the output current of the first transformer **34** is I_2, then the magnetic flux produced by I_2 through the coil **134** induces an induction current I_F in the coil **135** given by

$$I_F=I_2(N_3/N_4) \quad (2)$$

From Equations 1 and 2, we have

$$I_1(N_1/N_2)=I_2(N_3/N_4)$$

$$I_2/I_1=(N_1/N_2)/(N_3/N_4) \quad (3)$$

Thus, the currents in the current paths are related to each other according to the coil turn ratios.

In FIG. **6**, the coil turn ratio in each transformer is 1 and, therefore, $I_1=I_2$. It should be appreciated that the drivers **22**, **24** must be capable of providing sufficient power to sustain the require currents. In FIG. **6**, the LEDs **152** and the LEDs **154** are of the same type (substantially the same optical and electrical characteristics). With the same current in each current path, the brightness of each LED is substantially the same. Furthermore, because the number of LEDs **152** and the number of LEDs **154** are the same, the overall brightness produced by the LEDs associated with each current path is also substantially the same. As shown in FIG. **6**, a resistor **62** is provided in the current path **52** so that a feedback signal can be obtained. However, the resister **64** in the current path **54** is optional.

If the LEDs in one current path are different from the LEDs in the other current path, it is possible to select transformers of different coil turn ratios to control the brightness of individual LEDs in a current path. For example, if the LEDs **152** in the first current path **52** are red and the LEDs **154** in the second current path **54** are green, it is possible to increase the brightness in the green LEDs by having a different coil turn ratio in the second transformer **34**. As shown in FIG. **8**, the coil turn ratio in the first transformer **32** is 1:1 and the coil turn ratio in the transformer **34** is 1:2. Accordingly, we have

$$I_g/I_r=(N_1/N_2)/(N_3/N_4)=1/(1/2)=2$$

or

$$I_g=2I_r$$

Furthermore, the overall brightness in green color can be increased by increasing the number of green LEDs **154** in the current path **54** without changing the driving circuit **10**.

FIG. **9** is an exemplary driving circuit for providing currents to three current paths of three different LEDs. As shown, the LEDs **152** in the current path **52** are blue, the LEDs **154** in the current path **54** are red and the LEDs **156** in the current path **56** are green. It is possible to select transformers **32**, **34** and **36** to provide currents I_b, I_r and I_g to drive the corresponding LEDs. For example, the coil turn ratio in the first transformer **32** is 2:3, the coil turn ratio in the second transformer **34** is 1:1 and the coil turn ratio in the third transformer **36** is 1:2. If the current in the current loop is I_F, we have

$$I_F=I_b(2/3)=I_r=I_g(1/2)$$

$$\text{or } I_b=(3/2)I_r$$

$$I_g=2I_r$$

If it is desirable to use red, green and blue LEDs to produce a white light source, it is possible to adjust the number of different color LEDs without changing the driving circuit **10**. It is also possible to use a pulse width modulation (PWM) IC, for example, to change the current in different color LEDs to achieve an optimum white light output (see FIG. **11**).

In a light source with a large source area, it is advantageous to use more than one current path to drive the LEDs of each color. As shown in FIG. **10**, a plurality of transformers are used to drive blue LEDs **152** in current paths $\mathbf{52}_1 \ldots \mathbf{52}_n$, a plurality of transformers are used to drive red LEDs **154** in current paths $\mathbf{54}_1 \ldots \mathbf{54}_m$, and a plurality of transformers are used to drive green LEDs **156** in current paths $\mathbf{56}_1 \ldots \mathbf{56}_k$.

FIG. **11** shows a driving circuit **10** having an inverter driver block **20'**, wherein power switches and transformers are used to convert DC power sources into AC power sources. The inverter driver block **20'** further comprises a

PWM IC **25** operatively connected to one of the power switches to adjust the current in various current paths in the light source **50**. As such, the overall brightness of the light source **50** can be adjusted with a pulse width modulator.

In sum, the driving circuit, according to the present invention, uses a plurality of transformers to provide currents to a plurality of current paths for driving a plurality of LEDs. Each of the transformers has two induction coils magnetically coupled through the transformer core. Each transformer has a coil turn ratio according to the number of turns in each induction coil. One induction coil is used to provide an output current to a different current path and the other induction coil is connected to the corresponding induction coil of other transformer for forming a current loop. As such, the output current of each transformer has a relationship with the output current of the other transformers depending on the coil turn ratios of the connected transformers.

What is claimed is:

1. A method to balance current flows in a light source operatively connected to an electrical circuit providing electrical power to the light source, the light source having at least a first current path, a second current path, one or more first light-emitting devices connected to the first current path, and one or more second light-emitting devices connected to the second current path, the first current path operatively connected to a first power source through a first rectifying means for receiving a first current, the second current path operatively connected to a second power source through a second rectifying means for receiving a second current, wherein a ratio of the second current to the first current is R, and wherein the electrical circuit comprises:

a first transformer operatively connected between the first power source and the first rectifying means, the first transformer having

a current providing coil for providing the first current, the current providing coil having a number of coil turns, and an induction coil magnetically coupled to the current providing coil for producing an induction current in response to the first current, the induction coil having a further number of coil turns with a first coil turn ratio between the number and the further number;

a second transformer operatively connected between the second power source and the second rectifying means, the second transformer having

a current providing coil for providing the second current, the current providing coil having a number of coil turns, and an induction coil magnetically coupled to the current providing coil for producing an induction current in response to the second current, the induction coil having a further number of coil turns with a second coil turn ratio between the number and the further number, said method comprising the steps of:

connecting the induction coil of the first transformer and the induction coil of the second transformer to form a current loop for the induction current in the first and second transformers;

selecting the first and second coil turn ratios such that the ratio between the first coil turn ratio and the second coil turn ratio is substantially equal to R.

2. The method of claim **1**, wherein the light source further has a third current path and one or more third light-emitting devices connected to the third current path, the third current path operatively connected to a third power source through a third rectifying means for receiving a third current, wherein a ratio of the third current to the first current is R', and wherein the electrical circuit further comprises:

a third transformer operatively connected between the third power source and the third rectifying means, the third transformer having

a current providing coil for providing the third current, the current providing coil having a number of coil turns, and an induction coil magnetically coupled to the current providing coil, the induction coil having a further number of coil turns with a third coil turn ratio between the number and the further number, said method further comprising the steps of:

connecting the induction coil of the third transformer to the induction coils of the first and second transformers to form the current loop for the induction current in the first, second and third transformers;

selecting the third coil turn ratio such that the ratio between the first coil turn ratio and the third coil turn ratio is substantially equal to R'.

3. A transformer circuit for use in a driving circuit having a power source and a rectifying section for providing currents to a light source, the rectifying section comprising a first rectifier and a second rectifier, the light source having at least

a first current path operatively connected to the first rectifier,

a second current path operatively connected to the second rectifier,

one or more first light-emitting devices connected to the first current path for receiving a first current from the driving circuit, and

one or more second light-emitting devices connected to the second current path for receiving a second current from the driving circuit, wherein a ratio of the second current to the first current is R, said transformer circuit comprising:

a first transformer operatively connected between the power source and the rectifying section, the first transformer having

a current providing coil for providing the first current, the current providing coil having a number of coil turns, and an induction coil magnetically coupled to the current providing coil for producing an induction current in response to the first current, the induction coil having a further number of coil turns with a first coil turn ratio between the number and the further number;

a second transformer operatively connected between the power source and the rectifying section, the second transformer having

a current providing coil for providing the second current, the current providing coil having a number of coil turns, and an induction coil magnetically coupled to the current providing coil for producing an induction current in response to the second current, the induction coil having a further number of coil turns with a second coil turn ratio between the number and the further number,

wherein the induction coil of the first transformer and the induction coil of the second transformer are connected to form a current loop for the induction current in the first and second transformers, and wherein a ratio between the first coil turn ratio and the second coil turn ratio is substantially equal to R.

4. The transformer circuit of claim **3**, wherein the rectifying section further comprises a third rectifier, the light source further having a third current path operatively connected to the third rectifier, and one or more third light-emitting devices connected to the third current path for receiving a third current from the driving circuit, wherein a ratio of the third current to the first current is R', said transformer circuit further comprising:

a third transformer operatively connected between the power source and the rectifying section, the third transformer having

a current providing coil for providing the third current, the current providing coil having a number of coil turns, and an induction coil magnetically coupled to the current providing coil, the induction coil having

a further number of coil turns with a third coil turn ratio between the number and the further number, wherein

the induction coil of the third transformer is connected to the induction coils of the first and second transformers to form the current loop for the induction current in the first, second and third transformers, and wherein a ratio between the first coil turn ratio and the third coil turn ratio is substantially equal to R'.

* * * * *